TABLE 4.—*Flood stages in the rivers of the Pacific slope, February, 1916.*

River.	Station.	Flood stage.	Above flood stage.		Crest stage.	Date.
			From—	To—		
		Feet.			*Feet.*	
Columbia	Vancouver, Wash	15.0	12	13	15.7	12
Willamette	Eugene, Oreg	10.0	7	9	18.2	7
Do	Albany, Oreg	20.0	8	10	28.0	8
Do	Salem, Oreg	20.0	8	10	26.2	9
Do	Oregon City, Oreg	12.0	8	14	15.0	10
Do	Portland, Oreg	15.0	9	14	20.0	11
Santiam	Jefferson, Oreg	10.0	7	8	14.9	7
Yamhill	McMinnville, Oreg	35.0	10	12	39.1	11
Clackamas	Cazadero, Oreg	8.0	7	8	11.9	7
Sacramento	Red Bluff, Cal	23.0	10	11	24.0	10
San Joaquin	Lathrop, Cal	17.0	7	7	17.0	7

TABLE 5.—*Flood stages in the tributaries of the Ohio, February, 1916.*

River.	Station.	Flood stage.	Above flood stage.		Crest stage.	Date.
			From—	To—		
		Feet.			*Feet.*	
French Broad	Asheville	4.0	3	3	4.0	3
Tennessee	Knoxville, Tenn	12.0	3	4	14.0	3
Monongahela	Fairmont, W. Va	25.0	13	13	25.0	13
Do	Greensboro, Pa	20.0	13	13	23.0	13
Do	Lock No. 4, Pa	31.0	14	14	31.7	14
Little Kanawha	Glenville, W. Va	22.0	13	13	22.5	13
Do	Creston, W. Va	20.0	13	13	20.6	13
Walhonding	Walhonding, Ohio	8.0	1	1	8.0	1
Scioto	Prospect, Ohio	10.0	1	2	10.9	2
Do	Circleville, Ohio	7.0	1	3	11.1	1
Miami	Tadmor, Ohio	12.0	[1] 31	1	14.8	1
Wabash	Bluffton, Ind	12.0	1	2	13.5	1
Do	Logansport, Ind	12.0	[1] 31	2	14.6	1
Do	La Fayette, Ind	11.0	[1] 29	5	23.5	2
Do	Terre Haute, Ind	16.0	[1] 31	8	23.0	2
Do	Mount Carmel, Ill	15.0	[1] 1	17	26.7	7

[1] January.

TABLE 6.—*Flood stages in the Missouri River and tributaries, February, 1916.*

River.	Station.	Flood stage.	Above flood stage.		Crest stage.	Date.
			From—	To—		
		Feet.			*Feet.*	
Missouri	Blair, Nebr	15.0	26	29	16.6	27
Blue	Beatrice, Nebr	16.0	18	18	18.0	18
Grand	Chillicothe, Mo	18.0	20	22	19.8	21
Osage	Bagnell, Mo	28.0	[1] 28	4	32.8	1

[1] January.

Hydrographs for typical points on several principal rivers are shown on Chart I. The stations selected for charting are Keokuk, St. Louis, Memphis, Vicksburg, and New Orleans, on the Mississippi; Cincinnati and Cairo, on the Ohio; Nashville, on the Cumberland; Johnsonville, on the Tennessee; Kansas City, on the Missouri; Little Rock, on the Arkansas; and Shreveport, on the Red.

SNOWFALL AT HIGH ALTITUDES, FEBRUARY, 1916.

An exceptionally heavy snow cover in the mountains accumulated during January, 1916. A severe snowstorm during the first few days of February, 1916, added a considerable amount in Oregon, Washington, Idaho, and in Montana, west of the Continental Divide. Subsequent weather, however, was not favorable to the conservation of the snow and by the close of the month much snow had disappeared from the lower levels up to 7,000 feet and on the south slopes. The remaining snow was well packed, and the outlook for irrigation and power water, though not so bright as at the close of the preceding month, was still favorable in practically all localities.—A. J. H.

RELATION OF PRECIPITATION TO STREAM FLOW IN MONTANA.

By R. FRANK YOUNG, Meteorologist.

[Dated: Weather Bureau, Dayton, Ohio, Feb. 14, 1916.]

The region under discussion in this paper is that portion of the northern Rocky Mountains which forms the headwaters basin of the Missouri-Mississippi drainage. It is outlined in figure 1, below.

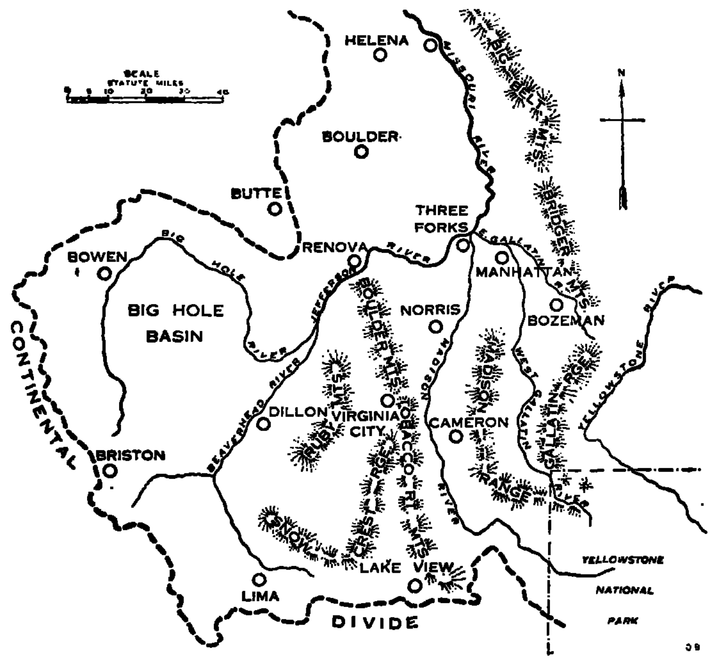

FIGURE 1.—Sketch map of the headwaters of the Missouri in Montana.

Investigations of the water resources in the Rocky Mountains have generally proceeded on the assumption that the most important, if not the only important influence controlling the summer flow of streams is the amount of snow accumulated in the mountains at the close of the snow season. The facts here presented seem to warrant the statement that the question is one of somewhat greater complexity than this view recognizes; but fortunately the greater complexity of the problem does not necessarily add to the difficulty of its solution. The great amount of labor involved in the measurement of the depth of snow over large areas, and the unavoidable inaccuracy of measurements of drifted snow, which may vary in depth from a few inches to 50 feet or more, would probably render this method impracticable for the northern Rocky Mountain region as a whole. Fuller investigation may show that more reliable estimates of the amount of moisture stored in the mountains can be made from careful and well distributed records of precipitation and temperature, supplemented by evaporation measurements, than from any number of measurements of snow on the ground. This applies particularly to the eastern slope of the northern Rockies where the snow, as a rule, is nearly all blown into drifts, and where under normal temperature conditions there is practically no loss except by evaporation during the winter months.

TABLE 1.—*Average monthly departure from normal of stream flow at Canyon Ferry, Mont., and of precipitation and temperature over the watershed above Canyon Ferry.*

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1903.												
Streamflow (cu. ft./sec.)	− 110	− 770	−1,630	−1,690	−2,180	− 3,710	−1,560	− 940	− 870	−1,100	− 800	+ 230
Precipitation (in.)	−0.13	− 0.38	+ 0.06	+ 1.30	− 1.09	− 0.60	+ 1.17	− 0.48	− 0.52	− 0.58	+ 0.58	+0.09
Temperature (°F.)	+ 4.6	− 3.2	− 1.0	− 1.0	− 3.3	+ 1.8	− 2.8	+ 0.4	− 2.4	+ 3.8	− 3.2	+ 1.0
1904.												
Stream flow (cu. ft./sec.)	+ 90	− 270	− 430	+ 10	+1,020	− 2,210	−1,560	− 940	− 570	− 800	− 800	− 270
Precipitation (in.)	−0.13	+ 1.11	+ 0.70	− 0.77	− 1.50	− 0.87	− 0.13	− 0.37	− 1.27	− 0.68	− 0.64	+0.11
Temperature (°F.)	+ 4.3	+ 1.0	− 1.5	+ 3.9	− 0.2	− 1.8	− 1.0	+ 0.4	+ 0.8	+ 4.0	+ 6.6	+ 2.7
1905.												
Stream flow (cu. ft./sec.)	+ 90	− 670	− 330	−1,690	−5,180	− 7,710	−2,060	−1,440	−1,870	−1,700	−1,100	− 370
Precipitation (in)	−0.41	− 0.40	− 0.04	− 0.24	− 0.41	+ 0.30	− 0.12	− 0.01	− 0.45	− 0.56	− 0.09	−0.35
Temperature (°F.)	+ 2.2	− 4.9	+ 6.4	+ 1.7	− 3.0	− 3.6	+ 0.4	− 1.2	+ 3.1	− 4.6	− 0.1	− 1.6
1906.												
Stream flow (cu. ft./sec.)	− 610	− 370	− 830	− 990	−1,680	− 5,710	−2,560	−2,060	+ 130	−1,000	− 900	+ 530
Precipitation (in.)	+0.01	+ 0.09	− 0.21	− 0.22	+ 0.50	+ 0.06	− 0.85	+ 1.18	− 0.54	− 0.58	+ 0.10	+0.22
Temperature (°F.)	+ 4.3	+ 5.5	− 6.0	+ 4.0	− 0.7	− 4.3	+ 2.1	− 0.8	+ 1.2	+ 3.0	− 2.3	+ 5.5
1907.												
Stream flow (cu. ft./sec.)	− 210	+ 830	+ 770	+ 910	+ 320	+ 3,290	+9,940	+2,060	+ 130	− 300	− 500	− 270
Precipitation (in.)	−0.21	+ 0.26	+ 0.58	− 0.46	− 0.75	+ 1.21	+ 0.88	+ 0.40	− 0.44	− 0.42	− 0,49	−0.14
Temperature (°F.)	− 8.8	+ 7.0	+ 3.8	− 0.9	− 2.0	− 4.5	− 1.7	− 3.2	− 0.1	+ 5.5	+ 3.2	+ 2.1
1908.												
Stream flow (cu. ft./sec.)	− 110	− 370	− 230	+ 510	−1,180	+11,290	+3,440	+ 60	+ 630	+1,300	+ 700	+ 530
Precipitation (in.)	−0.30	+ 0.07	+ 0.32	− 0.53	+ 4.17	+ 1.62	− 0.62	− 0.11	+ 0.01	+ 0.52	− 0.52	−0.40
Temperature (°F.)	+ 3.8	+ 3.3	+ 2.7	+ 4.1	− 1.7	− 4.5	+ 2.3	− 1.1	+ 2.2	− 1.4	+ 1.4	+ 0.1
1909.												
Stream flow (cu. ft./sec.)	+ 590	+ 530	+ 70	− 490	− 880	+ 3,290	− 60	− 440	+1,630	+ 700	+ 700	+ 30
Precipitation (in.)	+0.30	− 0.27	+ 0.59	− 0.08	+ 0.03	− 0.88	+ 1.28	− 0.02	+ 2.30	− 0.41	+ 0.95	+0.11
Temperature (°F.)	− 1.5	+ 3.5	+ 1.5	− 5.0	− 3.3	+ 0.2	− 0.1	+ 1.1	+ 1.4	+ 1.3	+ 1.8	− 9.0
1910.												
Stream flow (cu. ft./sec.)	+ 90	+ 130	+2,870	+2,510	+3,320	− 7,710	−4,560	−1,840	− 870	− 600	− 300	− 70
Precipitation (in.)	+0.26	+ 0.06	− 0.56	− 0.15	− 0.34	− 0.96	− 0.40	− 0.19	+ 1.03	+ 0.39	+ 0.64	−0.36
Temperature (°F.)	− 3.2	− 5.1	+ 9.9	+ 5.8	+ 1.7	+ 2.2	+ 2.9	− 1.7	− 0.9	+ 2.7	+ 1.4	+ 1.2
1911.												
Stream flow (cu. ft./sec.)	− 210	− 370	+ 70	−1,690	−1,980	+ 3,290	−1,060	− 440	− 370	− 300	− 500	− 470
Precipitation (in.)	+0.34	− 0.16	− 0.74	− 0.34	− 0.17	+ 1.01	− 0.69	+ 0.05	+ 0.01	+ 0.78	+ 0.07	+0.03
Temperature (°F.)	+ 2.0	− 3.5	+ 5.8	− 1.2	− 2.1	+ 0.9	− 2.0	− 3.3	− 2.7	− 2.5	− 5.9	− 2.3
1912.												
Stream flow (cu. ft./sec.)	+ 90	+ 430	− 930	− 390	+2,820	+ 5,290	+ 440	+1,560	+1,430	+1,400	+1,200	+ 530
Precipitation (in.)	−0.40	− 0.34	+ 0.21	+ 0.52	− 0.29	− 0.77	+ 0.12	+ 0.92	+ 0.05	+ 0.70	− 0.35	−0.20
Temperature (°F.)	+ 2.8	+ 3.2	− 9.4	+ 0.3	− 1.4	+ 1.4	− 3.2	− 3.2	− 6.1	− 2.9	+ 4.2	− 1.9
1913.												
Stream flow (cu. ft./sec.)	− 410	− 570	− 930	+2,010	+2,820	+ 6,290	+1,440	+ 560	− 370	+ 800	+1,100	− 170
Precipitation (in.)	−0.18	− 0.13	− 0.04	− 0.11	− 0.65	+ 2.50	+ 0.70	− 0.19	− 0.27	+ 0.56	+ 0.12	−0.50
Temperature (°F.)	+ 0.9	− 6.5	− 3.7	+ 0.9	− 0.4	+ 0.2	− 2.5	+ 1.4	− 0.1	− 3.3	+ 1.8	− 2.1
1914.												
Stream flow (cu. ft./sec.)	+ 580	+ 710	+ 310	+ 290	+3,420	− 2,010	−2,580	−1,325	− 540	+1,160	+ 620	− 180
Precipitation (in.)	−0.14	+ 0.06	− 0.62	+ 0.35	− 0.55	+ 1.01	− 0.14	− 0.95	+ 0.54	+ 0.56	− 0.58	−0.40
Temperature (°F.)	+ 8.3	+ 2.0	+ 4.6	+ 1.8	+ 0.1	− 1.9	+ 1.8	− 1.4	− 0.8	+ 1.8	+ 5.7	− 4.2
1915.												
Stream flow (cu. ft./sec.)	+ 130	+1,940	+1,220	+ 740	− 660	− 3,730	+ 680	+1,190	+1,480	+ 560	+ 520	+ 850
Precipitation (in.)	−0.10	− 0.22	+ 0.09	+ 0.06	+ 0.56	+ 1.56	+ 1.51	+ 0.02	+ 0.85	− 0.71	+ 0.12	....
Temperature (°F.)	+ 2.2	+ 7.6	+ 4.5	+ 7.8	− 1.6	− 5.7	− 4.6	+ 2.4	− 3.8	+ 4.0	− 0.8	....
Normal temperature and precipitation for the watershed above Canyon Ferry:												
Temperature (°F.)	**19.2**	**21.1**	**29.0**	**39.8**	**49.2**	**57.2**	**62.8**	**61.8**	**52.9**	**41.9**	**31.3**	**22.2**
Precipitation (in.)	**0.79**	**0.61**	**0.99**	**1.09**	**2.64**	**2.28**	**1.31**	**1.01**	**1.39**	**1.15**	**0.74**	**0.70**

TABLE 2.—*Average discharge of the Missouri River at Canyon Ferry, Mont.*

Years.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
	Cu. ft./sec.	*Cu. ft./sec.*	*Cu. ft./sec.*	*Cu. ft./sec.*	*Cu. ft./sec.*	*Cu. ft./sec.*	*Cu. ft./sec.*	*Cu. ft./sec.*	*Cu. ft./sec.*	*Cu. ft./sec.*	*Cu. ft./sec.*	*Cu. ft./sec.*
1903	2,800	2,600	2,800	4,300	7,000	11,000	5,000	2,500	2,500	3,000	3,300	3,500
1904	3,000	3,100	4,000	6,000	10,200	12,500	5,000	2,500	2,800	3,300	3,300	3,000
1905	3,000	2,700	4,100	4,300	4,000	7,000	4,500	2,000	1,500	2,400	3,000	2,900
1906	2,300	3,000	3,600	5,000	7,500	9,000	4,000	5,500	3,500	3,100	3,200	3,800
1907	2,700	4,200	5,200	6,900	9,500	18,000	16,500	5,500	3,500	3,800	3,600	3,000
1908	2,800	3,000	4,200	6,500	8,000	26,000	10,000	3,500	4,000	5,400	4,800	3,800
1909	3,500	3,900	4,500	5,500	8,300	18,000	6,500	3,000	5,000	4,800	4,800	3,300
1910	3,000	3,500	7,300	8,500	12,500	7,000	2,000	1,600	2,500	3,500	3,800	3,200
1911	2,700	3,000	4,500	4,300	7,200	18,000	5,500	3,000	3,000	3,800	3,600	2,800
1912	3,000	3,800	3,500	5,600	12,000	20,000	7,000	5,000	4,800	5,500	5,300	3,800
1913	2,500	2,800	3,500	8,000	12,000	21,000	8,000	4,000	3,000	4,900	5,200	3,100
1914	3,490	4,080	4,740	6,280	12,600	12,700	3,980	2,120	2,830	5,160	4,720	3,090
1915	3,040	5,310	5,660	6,730	8,520	10,980	7,240	4,630	4,850	4,660	4,620	4,120

Perhaps the most striking facts disclosed by this correlation of data on stream flow and precipitation are: (1) An excess of snow in the mountains at the close of the snow season does not give assurance of a normal stream flow during the following summer; (2) neither a heavy winter snowfall nor a large accumulation of snow in the mountains in spring is essential to a normal summer stream flow.

There are several instances in which the data of Table 1 support these statements, but two of the most striking will serve to illustrate the points. The autumn and winter of 1909–10 were unusually favorable for the storage of moisture in the form of snow in the mountains of the upper Missouri watershed, and at the close of February, 1910, all available information showed a marked excess in the stock of snow. Nevertheless while careful measurements by the Montana Power Co. showed the stream flow at Canyon Ferry from March to May, inclusive, was decidedly in excess of the normal, there was a yet more marked deficiency from June to August. In this case there is a very plausible explanation in the fact that both March and April, 1910, were abnormally warm and dry, and before the middle of the latter month all snow in the mountains except scattered drifts, which were of little consequence, had disappeared. The loss during these months, both by run-off and evaporation was excessive, and there was no excess in precipitation during May and June to offset this loss.

In 1914–15 practically the reverse of these conditions obtained. There was a marked deficiency in the late autumn and winter precipitation and less snow in the mountains at the close of winter than for many years. There were, however, similar temperature conditions in March and April, which were much warmer than normal in 1915 as in 1910. This of course tended to accentuate the shortage of snow. Apparently the only effect of this very unusual lack of snow was a marked deficiency in water during the flood stages of May and June.

The explanation of this is of general application to the northern Rocky Mountains, especially the eastern slope. In discussing the abnormal conditions existing at that time the following comment was made in the Montana snow bulletin for March, 1915:

While the winter snowfall is important as a rule in its effect on the summer stream flow, it is not always, and perhaps not as a rule the controlling factor in the supply during the low water period of July, August, and September. An excess of snow in the mountains is reflected to a greater extent in the May and June flood stages than in the low-water stages in July and August. After a winter of normal or excessive snow accumulation, the snow from the foothills and southern slopes disappears during March and April. The effect of the water from the snow that melts during this early period, upon the late flow of the streams will depend on the condition of the ground at the time of melting. If the ground beneath the snow is frozen to a considerable depth, only a small percentage of the water will seep into the soil, to appear later as ground water. As the season advances the melting gradually extends to higher altitudes and to the north slopes, and the maximum run-off is reached late in May or early in June, when the effect of the comparatively heavy rains of these months is combined with that of the melting snow. During these months the ground is fairly well saturated, and normally there is sufficient moisture for agricultural purposes without irrigation, and this surplus water in the streams is not utilized except in a few instances to fill storage reservoirs.

Following a winter of deficient snowfall the entire surface of the ground at lower altitudes becomes free from frost and comparatively dry by the middle of April, and is in condition to absorb the maximum amount of moisture during the wet season, comprising May and June. The water thus absorbed, to a large extent, reaches the streams at a later period when most needed to offset the deficiency from winter snow.

In the final paragraph of the bulletin it was stated that—

The foregoing facts seem to forecast without reasonable doubt that the flow in all streams during the period of high water in May and June, 1915, will be far below normal; but with an excess, or even normal, May and June rains to replenish the ground sources of water supply, the late flow will not likely show a corresponding deficiency.

As was clearly anticipated in this statement, the May and June stream flow was deficient, although May was moderately wet and June and July were excessively so. The excess in stream flow began with July and the percentage of excess increased through August and September; the October and November flow was much above normal notwithstanding that the precipitation was only slightly above normal after July.

SUMMARY.

While the data at present available may not be conclusive on all points, it is believed that the following facts are more or less clearly brought out:

The main supply for the streams during most of the year is ground water. The only conditions under which surface run-off has a marked effect are (1) an abnormally warm March and April, following a winter of heavy snow, or (2) excessive May and June rains coming while there is still much unmelted snow in the mountains.

A uniform snow cover over the entire watershed would better serve to replenish the ground sources than the same amount accumulated in drifts; so that a forested area, by preventing drifting as well as rapid melting and evaporation, is a better conserver of the water supply than is an open country.

The condition of the ground beneath the snow, whether frozen or free from frost, is an important factor in run-off control.

The slight fluctuation in winter stream flow lends support to the inference that under normal conditions there is no material loss by run-off during this season, and that therefore the amount of water stored in the mountains at the close of winter is approximately what falls from November to February, inclusive, minus the loss by evaporation.

MEAN LAKE LEVELS DURING FEBRUARY, 1916.

By UNITED STATES LAKE SURVEY

[Dated: Detroit, Mich., Mar. 3, 1916.]

The following data are reported in the Notice to Mariners of the above date:

Data.	Lakes.			
	Superior.	Michigan and Huron.	Erie.	Ontario.
Mean level during February, 1916:	*Feet.*	*Feet.*	*Feet.*	*Feet.*
Above mean sea-level at New York	602.44	579.47	571.99	245.41
Above or below—				
Mean stage of January, 1916	−0.15	+0.25	+0.31	+0.36
Mean stage of February, 1915	+0.75	−0.09	+0.63	+0.42
Average stage for February, last 10 years	+0.70	−0.53	+0.31	−0.31
Highest recorded February stage	−0.04	−3.25	−1.76	−2.26
Lowest recorded February stage	+1.68	+0.30	+1.36	+2.42
Average relation of the February level to:				
January level	−0.2	0.0	−0.1	+0.2
March level	+0.2	0.0	−0.1	−0.2

ERRATA.

Please make the following changes in the statistics for the floods as published in this REVIEW for January, 1916:

Page 30. Column 1, next to last line, *for* "Greenville, 57.3 feet" *read* "Greenville, 50.6 feet."

Page 30. Column 1, last line, change to read "was overstopped by 0.1 foot."

Page 31. Table 2, Crest stage at Newport, Ark., *for* "33.4 feet" *read* "34.3 feet."

Page 32. Table 6, last line, *for* "Jan. 17, stage 51.8 feet" *read* "Feb. 17, stage 53.4 feet."

Page 33. Table 9, Crest stage at Melville, La., *for* "41.9 feet on Mar. 1–4" *read* "43.2 feet on Feb. 14."